On the Half-Life of ^{44}Ti in Young Supernova Remnants

Eric B. Norman and Edgardo Browne

^{44}Ti is one of the few long-lived γ-ray emitting nuclides produced in substantial amounts during a supernova explosion. Its characteristic 1157-keV γ ray was observed from the young supernova remnant Cassiopeia A [Cas A] and from supernova remnant RXJ0852.0-4622. In order to deduce the mass of ^{44}Ti ejected in these explosions using the observed γ-ray fluxes, one needs to know their ages and distances as well as the half-life of ^{44}Ti. For Cas A, historical records indicate that this supernova exploded in about 1680. For RXJ0852.0-4622, estimates of the age range from 680 to 1500 years. In the laboratory the electron-capture decay of ^{44}Ti takes place with neutral atoms. For a neutral ^{44}Ti atom, the probability of electron capture from the K (1s) shell is 0.8891 and from the L-shell (2s) is 0.0960. Therefore, neglecting electron screening, for a charge-state 19^{+} ^{44}Ti ion (i.e. one electron in the 2s shell) its half-life would be (60yr / 0.9371) = 64 years. For a charge-state 20^{+} ion its half-life would be (60yr / 0.8891) = 67.5 years, and for a charge-state 21^{+} ion its half-life would be (60yr / 0.4446) = 135 years. Finally, for a charge-state 22^{+} ^{44}Ti ion, electron capture decay would not be possible and the nucleus would become stable.

The question thus arises as to how many electrons would be bound to a ^{44}Ti nucleus under the conditions of temperature and density found in a young supernova remnant. Assuming thermal equilibrium has been reached, at a temperature T and electron density N_e, the average number of bound atomic electrons in the atomic orbital with principal quantum number n is can be easily calculated. Using the observed temperatures and densities for these two supernova remnants leads to the conclusion that ^{44}Ti should be completely ionized (and thus stable) under the conditions that exist in these supernova remnants. However, the decay of ^{44}Ti in these remnants has been observed. Consequently, not all of the ^{44}Ti present in these objects is subject to such extremes of temperature and density. By fixing one of the parameters (e.g. mean electron density) at a measured value, one can calculate the maximum temperature at which, for example, there would be two K electrons and one L electron bound to a ^{44}Ti nucleus. Results of such calculations suggest that ^{44}Ti would be highly ionized even at the lower range of temperatures inferred for CasA and RX J0852.0-4622. In order to estimate the mass of ^{44}Ti ejected by these two supernovae, one must take the present-day observed gamma-ray fluxes and extrapolate them backward in time to the date of the explosion. Figure 1 shows this extrapolation for the values of the ^{44}Ti half-life previously calculated for four ionization states. For RX J0852.0-4622 the possible ^{44}Ti mass ejected by this supernova varies by a factor of 33 depending on the ionization state. Note that using the laboratory value for the ^{44}Ti half-life leads to the largest possible mass of this radioisotope ejected by a supernova. Thus, we conclude that as the result of a possible lengthening of the ^{44}Ti half-life due to ionization effects, the mass of ^{44}Ti ejected from a supernova and deduced from a gamma-ray measurement constitutes only an upper limit.